Cost-based assessment of NGOA architectures and its impact in the business model

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The increasing bandwidth demands and the strong service competition between different providers, are the main drivers that force providers to have a close evaluation of their costs as well as of the considered business model. One of the objectives of the European FP7 research project Optical Access Seamless Evolution (OASE) is to perform a techno-economic evaluation of different proposed solutions for Next Generation Optical Access (NGOA) Networks. The NGOA networks look to increase the bandwidth per user as well as increasing transmission reach so that the number of central offices can be reduced significantly. This paper presents a first study of five NGOA architectures in a green field deployment scenario. The evaluation comprises a cost assessment of infrastructure, network equipment and operational processes. The impact of actual business models is introduced.

Keywords - next generation optical access networks, cost evaluation, business models

I. INTRODUCTION

For the last years, demands for broadband services such as Video on Demand, Ultra High Definition Television, Cloud Computing or cloud-based services are increasing significantly. These services require sustainable bandwidths of up to 100 Mbps, which can only been supported by optical fiber access networks.

Fiber to the X (FTTx) infrastructure tends to migrate from fiber to the cabinet (FTTCab) to fiber to the Home (FTTH). FTTH infrastructure is deployed on a large scale in Asia [1], USA [2], and recently is picking up pace in Europe [3]. Furthermore, Next Generation Optical Access (NGOA) Networks seek to complain with new requirements such as long reach (more than the actual 20kms), high client count (256…1000) and high sustainable bit rate (up to 1 Gbps per user). Several technologies and architectures are candidates to cope with these requirements. Operators are evaluating them in detail to decide which one is the most cost effective and provides simple migration paths from current platforms and technologies [4]. Their evaluation should include the cost assessment for different types of areas and fiber roll-out scenarios, as well as different business models. The business models include the market competition among different providers as well as different related cost sharing. Furthermore, operators are evaluating the possibility to reduce the number of central offices in order to decrease costs [5]. However, this approach, which is known as node consolidation, is only possible when the architecture and technology supports the required transmission reach. These studies are targeted by the European project OASE [6] and this paper presents the first results.

The remainder of this paper is structured as follows: Section II introduces the different NGOA architectures considered in this study. In Section III, the modeling of the different costs included in the assessment is presented. Section IV describes the considered case studies and obtained results while Section V discusses the different business models and how they impact the cost from an operator perspective. Finally, Section VI concludes the paper with a discussion on future work.

II. NGOA ARCHITECTURES

Different architectures have been proposed as candidates to offer the high sustainable bandwidth per user required by new services [7]. These architectures are Fiber to the Home (FTTH) solutions and consist of an Optical Line Terminator (OLT) located at the provider's central access node (CAN), Optical Network Terminals (ONT) at each user's home and one or two Remote Nodes (RNs) depending on the architecture, which can contain passive or active components. The location of RN1 and RN2 is respectively corresponding to street cabinet and central office (or local exchange office) in a legacy telecom network. These elements are shown in Figure 1. The NGOA architectures covered in this study are:

A. *Wavelength routed WDM PON (WR-WDM PON)*

This architecture assigns one wavelength to each user of the network. It consists of the conventional components of a Passive Optical Network (PON): (i) an OLT, (ii) ONTs at each user's home; (iii) one RN equipped with wavelength filter between user and CAN to form the point-to-multipoint network topology, and optional (iv) one RN with Reach Extender (RE). The deployment of RN1 and RN2 can be flexible: either separated or collocated according to the network dimensioning. In this architecture, as shown in Figure 1 (a), Arrayed Waveguide Gratings (AWGs) are used at the RN1 for wavelength selection. The use of C/L and S/L band splitters and a spacing down to 25-GHz allow client counts of 80, 160 and 320. The reach of the system depends on the used ONT receiver and whether pre-amplifiers and/or booster are used in the OLT or not. In case of PIN based receivers, 160 wavelength channels and no pre-amplifiers or boosters in the OLT the reach is about 23 km assuming 0.34 dB/km fiber attenuation (1550 nm) as well as margins for splices and connectors. When using APD based receivers and OLT pre-amplifiers and boosters, the reach is about 52 km assuming a system configuration with 160 wavelength channels

B. *Ultra Dense WDM PON (UDWDM PON)*

By using coherent heterodyne reception and ultra-dense wavelength channel spacing the UDWDM PON concept enables high transmission reach and high split ratios [8].

In our model the UDWDM PON architecture uses two RN (Figure 1 (b)). One RN contains an AWG, which splits the UDWDM signal into a number of wavebands. The second RN contains a power splitter and all ONTs connected to one power splitter receive all UDWDM channels included in the waveband. The ONT negotiate with the OLT which UDWDM channel it should use. The concept would also be feasible with pure power splitter based RNs at the cost of a decreased link budget and decreased reach. Reach extenders can be optionally included in active RN for increasing the transmission distance. The client count support for this system can be up to 320 and 640, implemented using 20 port AWGs with 1:16 power split ratio or 40 and 80 port AWGs followed by 1:8 power splitters. The reach of the system is about 50km for both AWG/power splitter configurations.

C. *Hybrid PON (HPON)*

HPON shown in Figure 1(c) combines the wavelength routing capabilities of an AWG at the first RN, with a power splitter at the second RN. Per-wavelength Time-Division Multiplexing (TDM) is used for the downstream, while Time-Domain Multiple Access (TDMA) with tunable burst-mode transceivers is used in the upstream to support a symmetrical 10 Gb/s per wavelength. Architectural options include 40- and 80-port AWGs, which are followed by 1:32 or 1:16 power splitters, allowing 640 or 1280 clients feeder fiber (FF) respectively. The reach of the HPON system is between 17 km (40 wavelengths, 1:32 power split, APD based ONT) and 27 km (40 wavelengths, 1:16 power split, APD based ONT). Also for the HPON concept reach extenders basing on optical amplifiers can be used for increased transmission distances.

D. *Two-stage WDM PON*

Two-stage WDM-PON architecture as shown in Figure 1 (d) consist of two layer of WDM PON system, one embedded to the other. In the first stage, a WDM OLT-1, which is similar to the OLTs used in wavelength-routed WDM PON, is located in RN2. It connects multiple home ONTs via an AWG with “N” channel wavelength. The AWG is located at fully passive RN1, it aggregates “N” ONTs into one fiber which is terminated at OLT-1. The OLT-1 then is backhauled by the second stage WDM PON system. The OLT of the second WDM-PON (OLT-2) is placed at CAN. An “M” channel AWG can be either collocated with OLT-1s at RN2 (considered in this study) or placed at another passive RN between the RN2 and CAN to have more flexibility of aggregating several RN2s. In this study we assume each ONT has 1Gb/s interface, “M” and “N” are equal to 80, the uplink interface of OLT-1 and downlink interfaces of OLT-2 are 10Gb/s. The use of electronic traffic aggregation in the OLT-1 and WDM based transmission allows for effective multiplexing and a high client count in the feeder network between OLT-1 and OLT-2. Furthermore the reach of the system can be quite high (40…80 km), depending on the used pluggable at the OLT uplink.

E. *Active Optical Network (AON) backhauled by WDM*

Similar to the two-stage WDM-PON architecture described above, AON backhauled by WDM system as shown in Figure 1 (e) also consist of two stages. In the first stage a point to point (PtP) architecture which connects each subscriber via a dedicated fiber from home to Ethernet switches (OLT-1) at RN2. In the second stage, these switches are backhauled by a WDM PON system which is similar to what is discussed for two-stage WDM-PON. In this study 1Gb/s optical interfaces

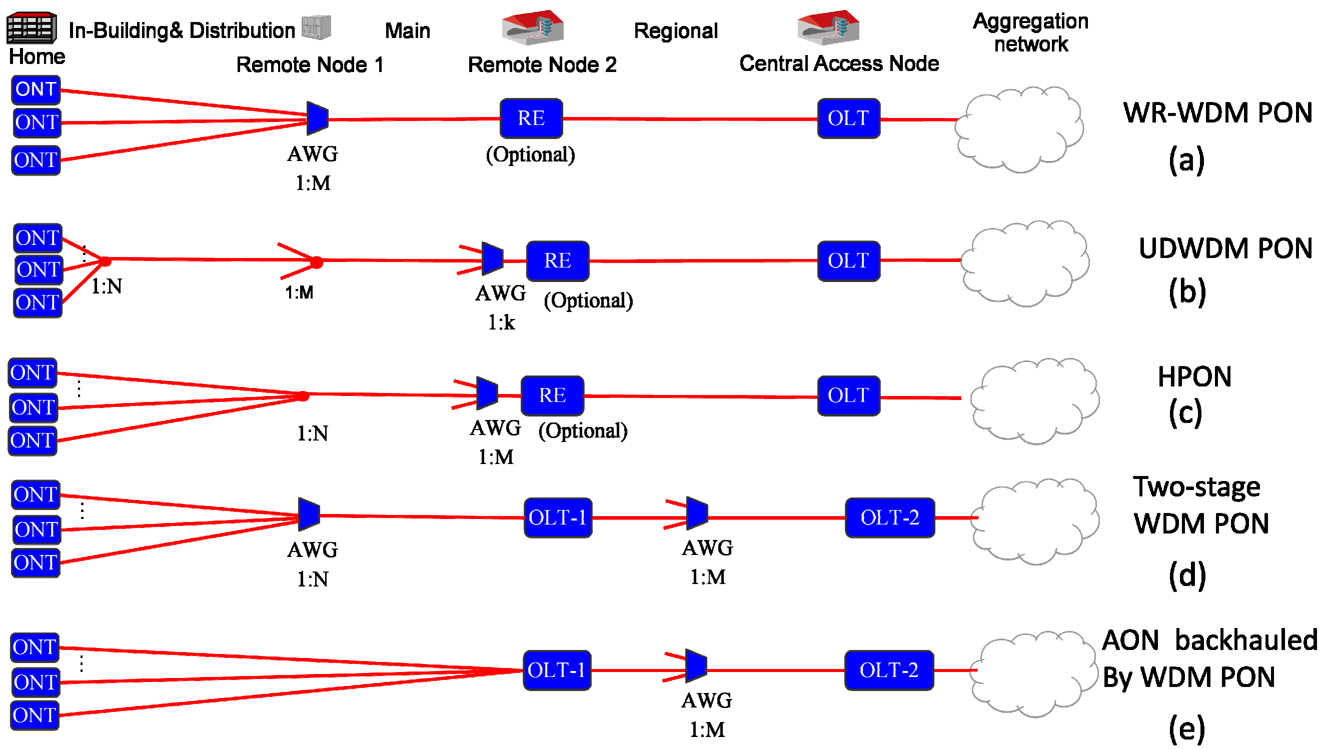

Figure 1: Next generation optical access architectures

are adopted for the link between ONT and OLT-1; 10Gb/s coloured interfaces are used for the uplink of OLT-1 and downlink of OLT-2. AWGs of 80 channel capacity are considered collocated with OLT-1 at RN2. The client count and the maximum transmission distance between OLT-1 and OLT-2 are similar to the two-stage WDM PON concept.

III. COST MODELING

The cost assessment performed on these architectures takes into account the following costs:

- Infrastructure cost: The network infrastructure required for each architecture depends strongly on the number and location of the remote nodes as well as the type of area (i.e. rural, urban or dense urban). Infrastructure costs include cable costs as well as the trenching, duct and micro-duct costs. Trenching costs distinguish in-building from street trenching. Furthermore, it has been advised that fibers should share as much as possible cables so that trenching costs, which are the most critical ones, are reduced [9].
- Equipment cost: The shopping list resulting from the network dimensioning is directly related to the equipment costs. The cost of existing equipment should be extrapolated to the time of implementing the NGOA network based on learning curves. The same happens with the equipment that will certainly be developed in the coming years. Equipment costs distinguish ONT, Optical Distribution Frame (ODF), RN and OLT costs. The RN can contain passive components (such as power splitters or AWG) or active components (such as Ethernet switch) depending on the architecture.
- Power consumption cost: The abovementioned shopping list can also be used to compute the power that will be consumed per year. Depending on the country, the current prices and the cost increase predictions, the cost associated the required consumed power can be calculated.
- Fault Management cost: Reliability of network components and infrastructure has an impact of the fault management cost. A detailed fault management process has been proposed [10] which distinguishes three main steps: detection, repair and restoration. Detection depends on the diagnosis methodology and available help lines. Repair depends on the traveling time, the number of required technicians, the replacement of the failed component (or repair when possible), etc. Finally, restoration deals with the required testing before closing the fault management process.

  The cost associated to the repair is proportional to the repair time and their salaries. The repair time of component *i* ($T_{rep\ i}$) is the time associated to the failure repair of this component, which can be expressed as $T_{rep\ i} = team_i.(MRT_i + 2.t_{travel\ i})$, where $team_i$ denotes the number of persons of the repair team, MRT_i denotes the Mean Repair Time of that component, which is the time required for the repair itself once the team is at the failure location; and $t_{travel\ i}$ denotes the traveling time from OLT to component *i,* which depends on the type of area. The repair time of a cable cut depends on the number of fibers in the cable.

The TONIC tool [11] (TechnO-ecoNomICs of IP optimised networks and services) is a tool that was developed to perform CapEx evaluation for traditional access networks. This tool has been used as a framework in OASE so that the different developed models were implemented and integrated within TONIC. The input cost values themselves are included in a database which has been updated based on the data required by the operational processes as well as data of equipment used in NGOA networks. This information was available from the OASE project partners [5].

IV. CASE STUDIES AND RESULTS

This study compares the different cost aspects of the presented architectures in two areas: dense urban area (DU) and rural (R) area. DU areas have higher user density than rural (2900 and 53 users/km^2 respectively). The considered DU area covers 5 km^2 and has 14500 users; whereas the R area covers 57 km^2 and 3060 users. All network architectures are designed to offer 300Mb/s (except for 2-stage WDM PON offering 250Mb/s) sustainable bandwidth to every subscriber.

The cost values are given as cost units per user, where one cost unit (CU) corresponds to the cost of a GPON ONT (Table 1). The cost of power consumption and fault management is given for a network lifetime of 10 years. Values for cost and power consumption of the equipment can be found in [5].

Table 1: Parameters

Technician salary	1,05 CU/hour
Power	54CU/kWh
Trenching DU	800CU/km
Trenching R	600CU/km
Trenching &cabling (In-house)	16CU/km

By comparing the cost of dense urban to rural area (Figure 2: Cost assessment of NGOA architectures in a dense urban area (green field) and Figure 3: Cost assessment of NGOA architectures in a rural area (green field)), we can see the geographical difference has little impact on the equipment related costs. For example the equipment cost, power consumption, and fault management cost of equipment are very similar for both dense urban and rural. However the infrastructure related costs are affected especially for the trenching cost, in the rural area trenching has significant higher cost in contrast to dense urban area, due to the longer trenching distance and less subscribers to share the costs. It is also notable that the trenching cost is more dominant in both dense urban and rural cases than other cost aspects, and it is particularly true in the rural area. That is same for all architectures in a green field deployment scenario. However if in a brown field case different architecture can differs from each other depending on the number of cables are required and the number of existing ducts are available for new deployment.

The ODF and fiber management cost at CAN is little, this is because all architectures are utilizing the WDM technology in the feeder fiber part (from RN2 to CAN), the number of feeder fibers actual connected to CAN is small.

RN. On the other hand, thanks to the maturity of the Ethernet technology, the equipment cost is lower than others.

The power cost includes all active equipment power consumptions, (e.g. OLT, ONT, cooling equipment, etc.). It shows large variance (see Figure 2: Cost assessment of NGOA architectures in a dense urban area (green field)) among different technologies; however the main difference comes from the ONT power which counts large percentage of total power consumption of the network. If the ONT power is analysis separately, we can see the AON with WDM backhauling architecture and 2-stage WDM PON has large power cost than others, due to the energy cost at active remote node.

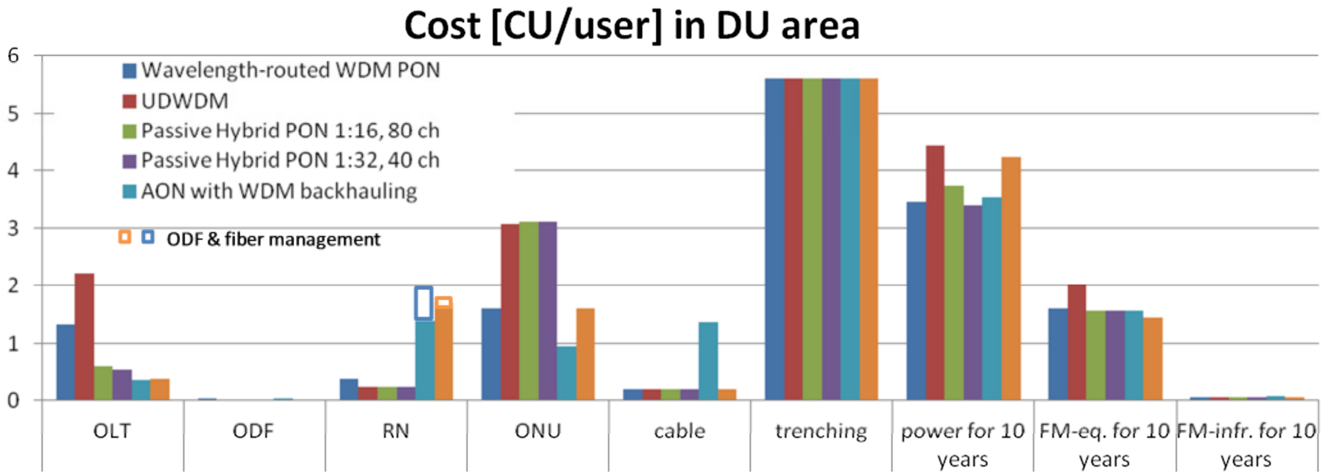

Figure 2: Cost assessment of NGOA architectures in a dense urban area (green field)

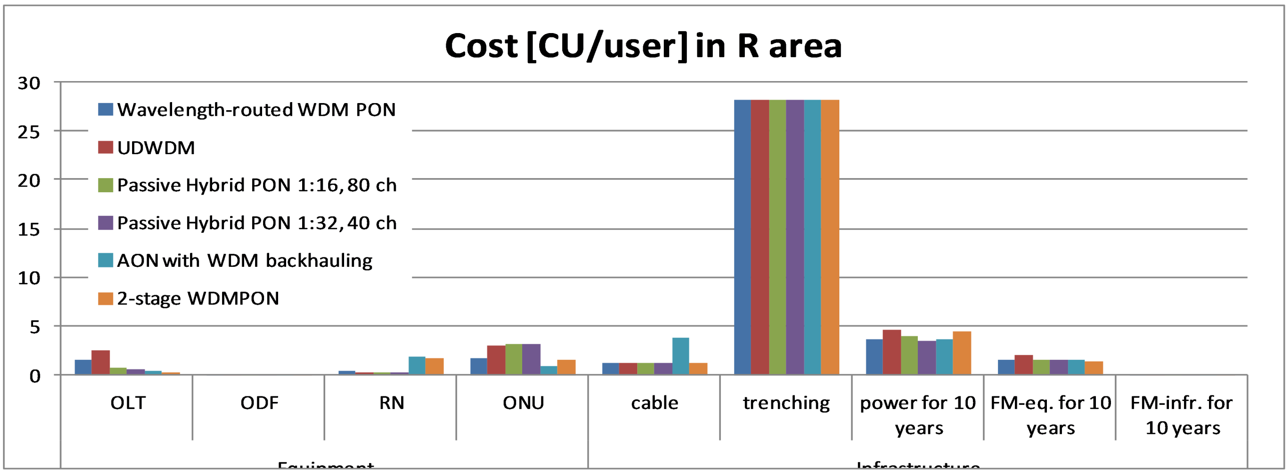

Figure 3: Cost assessment of NGOA architectures in a rural area (green field)

The RN cost of 2-stage WDM PON and AON with WDM backhauling architecture is much higher than others. One of the reasons is that the WDM backhauling solution requires active remote node which has higher cost (e.g. housing, power) to build than passive RN. Also the RN cost for these two WDM backhauling solutions include the active equipment cost in contrast to the other three architectures only passive components included in the RN. We also notice that the fiber management cost for AON with WDM backhauling architecture in RN account for a large portion, about 25% of overall cost at RN when a simplified ODF is applied (see Figure 4 blank rectangular bar); while in two-stage WDM PON case this figure is only 4%. If a complex ODF model is applied at RN for the AON case (for example opening fiber accessibility to multiple operators) the cost of fiber management will increase considerably.

As the AON with WDM backhaul solution has higher fibers need from users to RN2 due to its PtP topology. Therefore it has more cable cost and fiber management cost at CAN and

The fault management cost of equipment is similar for all architectures, except for UDWDM PON which is 20% higher than others. Most part of the cost is associated to the ONT failures. Although the repair of this equipment does not imply any technician, there is cost associated to the pre- and post-repair.

In terms of fault management cost of infrastructures, the AON with WDM backhauling solution has more cost than others because the fault of infrastructure involves more fibers repairing than other architectures. Furthermore, the cost associated per user is lower than other network costs.

V. Impact of Actual Business Setting

Cost results presented in the previous sections allow comparing costs for different NGOA architectures in typical geographical areas. This gives a good insight in the overall cost for the network deployment and operations in these scenarios.

In realistic network cases, e.g. in Stockholm and Amsterdam, however, these costs are not carried by a single actor [12]. Responsibilities are typically split in three conceptual levels. On the lowest level, the physical infrastructure provider (PIP) is responsible for right-of-way, ducts and fibers. The network provider (NP) is responsible for the OSI-layers 2 and 3 (including the wavelengths layer if applicable). On top of that, we can observe the service provider (SP), the costs for the service provider are not included in the current paper though. In the case of Stockholm the role of the PIP is taken up by Stokab (100% owned by the city of Stockholm), on top of that different NPs exist like OpenNet and Zitius (which do not connect the same buildings) as well as some integrated NP-SP players. In Amsterdam, the physical infrastructure provider role is taken up by Glasvezelnet Amsterdam (which was formed by a partnership between the city of Amsterdam, the housing associations and the private investors ING Real Estate and Reggeborgh), NPs are BBnet and KPN, the latter one integrated with the SP layer.

When mapping the definitions of physical infrastructure provider and network provider to the cost model from section III, we obtain a cost split per actor.

- The physical infrastructure provider cost consists of infrastructure costs and as well as equipment costs in the remote nodes. Basically, infrastructure cost consists of for cable, trenching and fiber and the related fault management, in practice this is basically repair cost in case of a cable cut. By extension this can also include potential costs for right of way (RoW, the right to open up the streets) as well as the blowing of fibers in case they are not directly deployed in ducts. Equipment cost in the remote nodes can be very different depending on the architecture at hand. Depending on the actual implementation per architecture, this can include power splitters, AWGs, etc as well as the provisioning of man- and handholes. Finally, the housing of the CO as well as the installation of empty racks can be included here.
- The network provider costs consist of the cost for the OLT and the ONU, including all related operational costs like power, cooling, floor space and fault management. Note that ONU power cost can be allocated to the end user as well.

A first rough estimate of the cost for PIP and NP obtained by summing the appropriate cost categories from the results in Figure 2 and Figure 3 is shown in Figure 4. Comparing the cost per user per actor (PIP or NP) over 10 years, we see that the majority of the cost is taken up in the PIP, in dense urban area it is about 50% of total cost for AON with WDM backhauling architecture and 30% for the other architectures; in rural area the figure reach to 75%. Therefore there is a large geographical impact on PIP than NP. NPs have more cost in dense urban area than PIPs. The operational cost for NP (accumulated for 10 years) is considerable, about 60% of the total cost. In contrast, the operational cost for a PIP is less since most of infrastructure is passive. The technology has a little impact on the infrastructure cost.

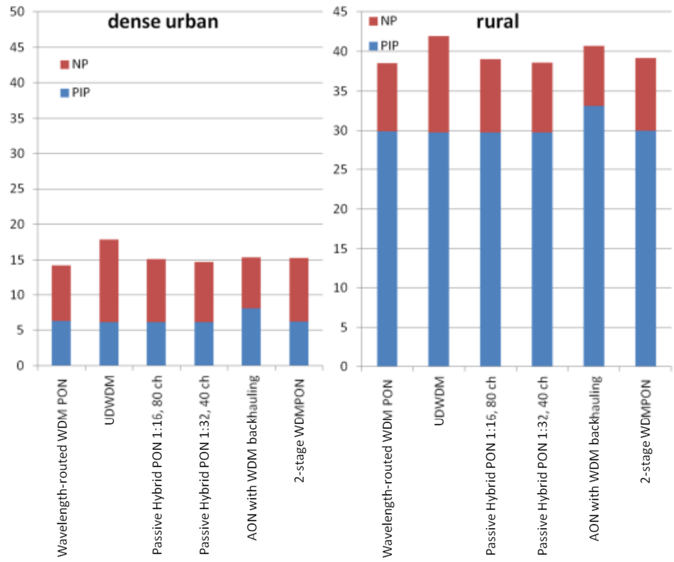

Figure 4: PIP/NP cost split

Given the very high infrastructure cost (basically trenching), it is clear that there is no sense in infrastructure-based competition on the fiber layer. Therefore, we can reasonably assume a single PIP per area. On the other hand, NP-based competition be realistic, e.g. the competition between KPN and BBnet in Amsterdam today. However, in order to allow for this type of competition, it is required to open up the network. Finally, competition on SP level is common in most examples. In practice this can be done in different ways

- Opening at the fibre layer means that different parallel fibres are available in the same cable / trench infrastructure, and that each NP therefore has at least one dedicated fibre to reach its customers. The provisioned element is the fibre. The network is opened at the PIP level. This model allows NP competition.
- Opening at the wavelength layer means that every NP/SP has access to one or more dedicated wavelength to reach the customers. The provisioned element is the wavelength and the model is opened at the PIP/NP level. Note that the mapping between customers and the wavelengths required to reach them is dependent on the architectural design and requires already in the deployment of the physical infrastructure consensus by all NP. In order to allow a user to connect to multiple NPs simultaneously, multiple transceivers are required. Those form the so-called provisioning interface. This model allows NP competition.
- Opening at the bitstream level means that there is a provisioned element on the OSI network layer 2 (Ethernet

or even TDMA) or layer 3 (MPLS, IP). Here also, the network is opened at the NP level, but on a horizontal level meaning that an access-granting NP operates the first mile independent from the access-seeking NP and the access-seeking NP depend on the available layer 2 or layer 3 product of the access-granting NP.

- Competition at SP level is possible in all scenarios.

All above mentioned NGOA architectures in section IV can be open for competition at bitstream level (horizontal split between access-granting and access-seeking NP at layer 2 or layer 3). In addition, opening at wavelength level through CAN to users' home can be implemented for WDM-PON and UWDM-PON, and 2-stage WDM PON. The AON with WDM backhauling architecture can have wavelength opening at CAN and fiber layer opening at RN2 for competitions. The implementation of open access will involve additional cost which will differ from each architectures and opening layers. For example for AON fiber layer opening at RN2 will require more complex ODF models (e.g. to offer full cross-connectivity).

VI. CONCLUSIONS

This paper presents a first study of five NGOA architectures in a green field deployment scenario, the selected architecture being wavelength-routed WDM PON, ultra-dense WDM PON, hybrid PON, two-stage WDM PON and active optical network backhauled by WDM.

The evaluation comprises a cost assessment of infrastructure, network equipment and operational processes. Fiber rich solutions like the AON with WDM backhaul solution have more cable cost and fiber management cost at CAN and RN. On the other hand, thanks to the maturity of the Ethernet technology, the equipment cost for AON is lower than others. Important cost differences are observed in the cost of the remote nodes, where the RN cost of 2-stage WDM PON and AON with WDM backhauling architecture is much higher than others.

By comparing the cost of dense urban to rural area, we can see the geographical difference has little impact on the equipment related costs. On the other hand infrastructure cost is clearly affected, primarily because of the higher trenching costs for bigger distances. Furthermore, the geographic factor has larger impact on PIP than NP, an operational cost is more important for NP than PIP.

The impact of actual business models is introduced, by indicating the cost split between the physical infrastructure provider and the network provider. In a competitive setting multiple NPs are to be expected in a single geographic area, requiring opening up the network at some logical level (fiber, wavelength or bitstream). It is clear that different architectures have different levels of flexibility in this regard.

Future work will extend the cost study results presented here and relate them to the expected revenues for the different actors (based on distances and number of customers for the PIP, based on bandwidth usage or other parameters for the NP) in order to be able to judge on the actual business case (cost-revenue comparison) for different scenarios (network architectures, geographic areas, etc).

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